A PRELIMINARY CLASSIFICATION SCHEME FOR THE CENTRAL REGIONS OF LATE-TYPE GALAXIES

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ABSTRACT

The large-scale prints in The Carnegie Atlas of Galaxies have been used to formulate a classification scheme for the central regions of late-type galaxies. Systems that exhibit small bright central bulges or disks (type CB) are found to be of earlier Hubble type and of higher luminosity than galaxies that do not contain nuclei (type NN). Galaxies containing nuclear bars, or exhibiting central regions that are resolved into individual stars and knots, and galaxies with semi-stellar nuclei, are seen to have characteristics that are intermediate between those of types CB and NN. The presence or absence of a nucleus appears to be a useful criterion for distinguishing between spiral galaxies and Magellanic irregulars.

1. INTRODUCTION

The Palomar Sky Survey was first published 40 years ago. It contained a very large and uniform database of rather small-scale galaxy images. Inspection of these photographs showed that both the degree to which arm structure was developed in spirals, and the mean surface brightness of irregular galaxies, correlated with luminosity (van den Bergh 1960a,b,c) The usefulness of the Palomar Sky Survey was, however, limited by the small scale of its images and by the fact that the central regions of many galaxies were "burned out" on the Survey prints. As a result, the characteristics of the nuclear regions of spirals could not be used as classification criteria. The recent publication of The Carnegie Atlas of Galaxies (Sandage & Bedke 1994), which contains large-scale images of the overwhelming majority of Shapley-Ames galaxies (Sandage & Tammann 1981), now makes it possible to classify significant numbers of galaxies on the basis of the characteristics of their central regions. For previous work on the structure and population content of the central regions of galaxies, the reader is referred to Morgan (1958) and Morgan & Osterbrock (1969).

2. A PRELIMINARY CLASSIFICATION SCHEME

In the present investigation, all images in Volume II (late-type galaxies) of The Carnegie Atlas of Galaxies were inspected in an effort to derive useful classification criteria. A total of 342 central regions of Shapley-Ames galaxies were classified and are listed in Table 1. Also given in this Table are the Hubble types of these galaxies taken from Sandage & Tammann (1981). In cases where these authors list two Hubble types, only the first one is given in the Table. Many images reproduced in the catalog of Sandage & Bedke could not be classified because (1) the central part of the galaxy was overexposed, (2) strong dust absorption made classification difficult or impossible, (3) the galaxy was peculiar because of recent tidal interactions, starbursts, etc., or (4) the galaxy did not fit in a natural way into the preliminary classification scheme that is proposed below. The following is a brief description of the adopted classification system: (Numbers in square brackets refer to the panel number in the Sandage & Bedke (1994) Atlas.)

NN Galaxy image contains no nucleus. The type example is NGC 2366 [327].

N Image contains a star-like nucleus. Good examples are NGC 991 [245], NGC 5949 [279], NGC 6207 [274] and NGC 6503 [288].

SSN Galaxy has a semi-stellar nucleus. Good examples of this type are NGC 300 [261] and NGC 7793 [321].

CB The galaxy is centred on a small bright central bulge or disk. The type standard is NGC 3726 [181]. Other good examples are NGC 1300 [154], NGC 1433 [158], NGC 2712 [165], NGC 3338 [173], NGC 4999 [159] and NGC 7038 [175]. In some cases (e.g. the Seyfert 1 galaxy NGC 4051 [180]), a semi-stellar nucleus is known to be present, but is not visible in the burned-out bulge of the image published by Sandage & Bedke (1994). In other cases, (e.g. NGC 1097 [201] and NGC 2903 [226]) the bright central region appears to be produced by a disk of HII regions and young OB stars, rather than by a bulge consisting of old or intermediate-age stars. In galaxies of types SBb and SBc, the central bulge may have a

non-circular outline.

NB In galaxies such as NGC 5112 [248], a nuclear bar-like structure is present in the galactic center. Other good examples of this type are NGC 672 [307], NGC 4116 [306] and NGC 5669 [2990].

Tr These are transitional objects that appear intermediate between spirals that have central bulges and objects having central regions that are resolved into stars and knots. Good examples are NGC 1313 [309] and NGC 4647 [278].

In the next section, some correlations between these classification types and other parameters will be examined.

3. LUMINOSITY DEPENDENCE OF CLASSIFICATION TYPES

Figure 1 shows a plot of galaxy magnitude MB [this is of Sandage & Tammann (1981), with Ho = 50 kms-1 Mpc-1 adopted for most distant galaxies] versus Hubble type for galaxies classified as CB. These objects, which have bright central bulges or disks, are seen to be strongly concentrated in the region with Hubble types Sb-Sc and MB < -20. [Galaxies with less certain classification types CB: are observed to have a slightly larger scatter in the magnitude versus Hubble type diagram.]

Figure 2 shows an absolute magnitude versus Hubble type plot for those galaxies in Volume II of the Sandage & Bedke (1994) Atlas which do not appear to have nuclei (types NN and NN:). These objects mostly have MB > -20 and are mainly of Hubble-de Vaucouleurs types in the range Sc-Sd-Im. Intercomparison of Fig. 1 and Fig. 2 shows that galaxies of types CB and NN occupy complimentary regions in the absolute magnitude versus Hubble type diagram. Galaxies without nuclei (type NN) are seen to have lower luminosities and later Hubble types than do galaxies with bright central bulges (type CB). Galaxies classified as being transitional (type Tr), and those with nuclear bars (type NB), have a distribution in MB versus Hubble type that is intermediate between those of CB galaxies on the one hand and objects of type NN on the other.

The difference between the luminosity distributions of galaxies classified CB and CB: and for galaxies of type NN and NN: in Volume II of The Carnegie Atlas of Galaxies is shown in Fig. 3. This Figure shows that CB galaxies, which have central bulges (and presumably nuclei embedded within them) are more luminous than NN galaxies which do not contain nuclei. The only two NN galaxies in the present sample that are more luminous than MB = -19.5 are NGC 4945 [285] in the Centaurus cluster (which is one of the most peculiar galaxies in the sky) and NGC 5490 [288].

4. NUCLEI AND GALAXY LUMINOSITY

Among spheroidal galaxies, the fraction of all objects that contains a nucleus increases dramatically towards higher luminosity (van den Bergh 1986). A similar relationship also appears to hold for disk galaxies. Fig. 4 shows a plot of the frequency distribution of irregular and spiral galaxies in a volume-limited sample of nearby galaxies compiled by Kraan-Korteweg & Tammann (1979). [For objects beyond the Local Group, the Sculptor Group and the M81 Group, their distances are based on the Ho = 50 km s-1 Mpc-1]. The Figure shows that spirals (which have nuclei) dominate among luminous galaxies with MB < -16, whereas irregulars (which do not contain nuclei) are most common among disk galaxies with MB > -16. The tendency for the brightest galaxies to be nucleated therefore appears to hold for both disk and spheroidal galaxies.

Among nearby disk galaxies, M33 (BT = -19.1), NGC 7793 (MB = -18.8) and NGC 300 (BT = -18.6) have semi-stellar nuclei, whereas the LMC (BT = -18.4), the SMC (BT = -17.0) and NGC 6822 (BT = -15.2) do not. This suggests a transition at BT ~ -18.5 between disk systems that do, and that do not contain nuclei. The fact that NGC 205 (BT = -15.7) and M32 (BT = -15.5) do have nuclei indicates that the transition between spheroidal galaxies with and without nuclei may, on average, take place at a fainter luminosity in ellipticals than it does in disk galaxies.

There are two well-known galaxies that appear to provide counter examples to the notion that spirals contain nuclei but that irregulars do not. These are the Large Magellanic Cloud and NGC 4449. The classification of these two systems will be discussed in more detail below.

4.1 The Large Magellanic Cloud

The idea that the LMC is a barred spiral was introduced by de Vaucouleurs (1954). Subsequently, de Vaucouleurs & Freeman (1972) showed that the long "spiral arm" that provided the strongest support for the SBm classification of the LMC was, in fact, a Galactic foreground feature. The classification of the Large Cloud as an irregular would be consistent with the observation that this object does not contain a nucleus. It is of interest to note that Magellanic irregular galaxies exhibit the same dichotomy between normal and barred objects that is encountered among spirals. The LMC is , perhaps, the best-known example of a barred irregular, whereas the SMC is a normal irregular. Since S0, spiral and irregular galaxies may occur as both normal and as barred objects, one should probably regard bar formation as a "flavor" that can occur among all disk galaxies. Among the relatively nearby galaxies listed in the Kraan-Korteweg & Tammann (1979) catalog, there is no significant difference between the luminosity distributions of barred and of unbarred disk galaxies.

4.2 NGC 4449

Hubble (1926, 1936) defined his morphological classification system for galaxies in terms of giant or supergiant type examples. In particular, he used the

luminous object NGC 4449 [326] as the type-example for irregular galaxies. In some ways, this choice of proto-type may have been unfortunate because NGC 4449, though lacking rotational symmetry, does appear to contain a well-developed (although not dominant) nucleus (see Fig. 5). It has become a source of some confusion that NGC 4449 was classified as Ir by Hubble (1936) in The Realm of the Nebulae and by Sandage (1961) in The Hubble Atlas of Galaxies, but as Sm by Sandage & Tammann (1981) in A Revised Shapley-Ames Catalog of Bright Galaxies. In fact, there appears to be a systematic deviation between the classification types of late-type galaxies assigned by Sandage & Tammann (1981) and those by other authors. Of the 17 Northern Shapley-Ames galaxies which van den Bergh (1960c) assigns to type Ir, only one (6%) are classified as an irregular by Sandage & Tammann (1981). These authors classify the remaining 16 objects as spirals. By the same token, only one (9%) of the 11 galaxies called Ir by Humason, Mayall & Sandage (1956) are classified as irregular by Sandage & Tammann (1981). However, if NGC 4449 is classified as a Magellanic irregular galaxy, then the apparent presence of a nucleus is an anomaly. Possibly, the "nucleus" of this object is, in fact, a more-or-less centrally located enormous HII region and star forming complex similar to that which is observed in the type NN galaxy NGC 4861 [327]. Clearly, it would be very interesting to test this hypothesis by making radial velocity studies of the central region of NGC 4449. Such observations could establish if the bright star forming complex in the galaxy is, or is not, its dynamical nucleus. The referee of this paper (Jay Gallagher) has emphasized the fact that some galaxies are known to have off-center bars and that some galactic nuclei might also be off-center.

5. SUMMARY AND CONCLUSION

Classifications have been made of 345 late-type galaxies in the Carnegie Atlas of Galaxies. Galaxies of type CB (which have small bright nuclear bulges or bright centrally located disks) are found to be both more luminous, and of earlier type, than are galaxies of type NN (which do not contain nuclei). It is suggested that the presence or absence of a nucleus in a late-type galaxy may be used as a criterion to distinguish in an objective fashion between spiral and irregular galaxies. It is also pointed out that galaxies of types (S0, Spiral, Ir) can occur in a normal or in a barred "flavor". The transition between systems with, and without, nuclei may occur at a fainter luminosity level for ellipticals than it does for disk galaxies.

I thank Chris Pritchet for providing me with a tape of our CFHT image of NGC 4449 and David Duncan for his help in producing Fig. 1. I am also indebted to Jay Gallagher for discussions about NGC 4449 and its nucleus, to Gerard de Vaucouleurs for references to early classifications of the LMC, and to Janet Currie for typing the manuscript.

Table 1 - Classifications of late-type galaxies

Galaxy	Hubble	Type	Galaxy	Hubble	Type	Galaxy	Hubble	Type	Galaxy	Hubble	Type
N24	Sc	Tr	N895	Sc	CB	N1512	SBb	CB	N2441	Sc	CB
N45	Scd	CB:	N925	SBc	NB:	N1518	Sc	NB	N2500	Sc	NB?
N95	Sc	CB	N941	Scd	Tr	N1536	SBc	NB	N2525	SBc	CB
N151	SBbc	CB	N958	Sbc	CB	I2056	Sc	N	N2523	SBb	CB:
N157	Sc	SSN:	N976	Sbc	CB:	N1559	SBc	NB	N2537	Sc	NN
N255	SBc	CB	N991	Sc	N	N1617	Sa	CB	N2545	SBc	CB
N247	Sc	Tr	N1035	Sc:	Tr:	N1659	Sc	SSN	N2552	Sc	NN
N255	SBc	CB	N1042	Sc	SSN	N1688	SBc	NB	N2608	Sbc	SSN:
SMC	Im	NN	N1058	Sc	CB:	N1744	SBcd	NB	N2642	SBb	CB
N300	Sc	SSN	N1073	SBc	NB:	N1796	SBc	NN	N2712	SBb	CB
N309	Sc	CB	N1079	Sa	CB:	N1784	SBbc	CB:	N2742	Sc	CB
New 1	SBc	CB:	N1084	Sc	SSN:	N1792	Sc	SSN	N2763	Sc	CB
N406	Sc	CB:	N1090	SBc	CB	HA85-1	Sc	CB	N2776	Sc	CB
N450	Sc	CB	N1097	SBbc	CB	LMC	SBm	NN	N2748	Sc	Tr
N470	Sbc	SSN	N1156	Sm	NN	N2082	Sc	Tr	N2835	SBc	SSN:
N514	Sc	CB	N1232	Sc	CB	N2188	Scd	NN	N2903	Sc	CB:
N521	SBc	CB	N1241	SBbc	CB	N2207	Sc	CB	N2942	Sc	SSN
N578	Sc	CB:	N1300	SBb	CB	N2223	SBbc	CB	N2907	S0	CB:
N625	Am	NN	N1313	SBc	Tr	N2339	SBc	SSN	N2976	Sd	NN
N628	Sc	CB	N1359	Sc	NB	N2276	Sc	SSN	N2998	Sc	CB:
N672	SBc	NB	N1376	Sc	CB:	N2336	SBbc	CB	N3003	Sc:	NB?
N685	SBc	CB:	N1433	SBb	CB	N2397	Sc	N?	N3059	SBc	NB:
N782	SBb	CB	N1437	Sc	CB	N2366	SBm	NN	N3041	Am	CB
I1783	Sbc	CB:	N1493	SBc	NB	N2427	Sc	NB?	N3052	Sc	SSN
N864	Sbc	SSN	N1494	Scd	Tr	N2442	SBbc	CB	N3054	SBbc	CB:

Galaxy	Hubble	Type	Galaxy	Hubble	Type	Galaxy	Hubble	Type	Galaxy	Hubble	Type
N3055	Sc	NB:	N3486	Sc	CB:	N3938	Sc	CB	N4234	SBc	NB
N3109	Sm	NN	N3495	Sc	Tr	N3949	Sc	CB	N4237	Sc	CB
I2537	Sc	CB:	N3511	Sc	N:	N3953	SBbc	CB	N4242	SBd	SSN
N3124	SBbc	CB	N3510	SBc	NB:	N3956	Sc	NB?	N4294	SBc	SSN:
N3145	SBbc	CB	N3513	SBc	NB	N3963	SBc	SSN	N4299	Sd	NN
N3184	Sc	CB	I2627	Sc	CB	N3992	SBb	CB:	N4303	Sc	SSN
N3200	Sb	CB	N3549	Sbc	SSN	I749	SBc	SSN	N4321	Sc	CB
N3259	Sb	SSN	N3556	Sc	NN?	N4041	Sc	CB	I3253	Sc	CB:
N3287	SBbc	NB	N3596	Sc	CB	N4062	Sc	SSN	N4389	SB	NB:
N3294	Sc	CB	N3614	Sc	CB	N4085	Sc	Tr?	N4385	SBbc	CB
N3318	SBbc	SSN	N3629	Sc	CB:	N4088	Sc	SSN	N4395	Sd	SSN
N3319	SBc	NB	N3646	Sbc	SSN	I2995	Sc	Tr	N4414	Sc	CB:
N3338	Sbc	CB	N3666	Sc	CB	N4096	Sc	CB	N4412	SBbc	SSN:
N3344	SBbc	CB	N3664	SBm	NB:	N4100	Sc	CB	N4449	Sm	NN
N3346	SBc	NB	N3686	SBbc	CB:	N4116	SBc	NB	N4535	SBc	CB
N3351	SBb	CB	N3687	SBbc	CB:	N4123	SBbc	CB	N4540	Scd	Tr
N3367	SBc	CB	N3691	S	NN	N4136	Sc	CB:	N4559	Sc	SSN
N3389	Sc	CB:	N3720	Sbc	SNN	N4145	SBc	CB	N4567	Sc	CB:
N3423	Sc	CB:	N3726	Sc	CB	N4162	Sc	CB:	N4571	Sc	CB
N3430	Sbc	SSN	N3732	Sc	N	N4183	Scd	Tr	N4580	Sbc	SSN
N3433	Sc	CB	N3738	Sd	NN	N4190	Sm	NN	N4592	Scd	Tr
N3445	Sc	Tr	N3735	Sc	CB	N4189	SBc	CB	N4593	SBb	CB
N3464	Sc	CB	N3780	Sc	CB	N4212	Sc	CB	N4595	Sc	SSN:
N3478	Sc	SSN	N3782	SBm	NN	N4219	Sbc	CB:	N4596	SBa	NB
N3485	SBbc	CB	N3877	Sc	SSN	N4236	SBd	NN	N4597	SBc	NN:

Galaxy	Hubble Type		Galaxy	Hubble Type		Galaxy	Hubble Type		Galaxy	Hubble Type	
N4602	Sc	CB:	N5068	SBc	NB	N5468	Sc	CB	N5907	Sc	CB
N4603	Sc	CB	N5085	Sc	CB	N5494	Sc	CB	N5921	SBbc	CB
N4632	Sc	Tr	N5088	Sc	Tr	N5530	Sc	CB	N5949	Sc	N
N4639	SBb	CB:	N5112	Sc	NB	N5556	SBc	NB	N5936	Sc	SSN:
N4647	Sc	Tr	N5156	SBbc	CB	N5585	Sd	CB	N5985	SBb	CB
N4653	Sc	CB	N5161	Sc	CB	N5584	Sc	SSN:	N5984	SBcd	NB:
N4656	Im	Tr:	N5204	Sd	Tr	N5597	SBc	CB:	N5967	Sc	CB
N4668	SBc	NN:	N5236	SBc	CB	N5605	Sbc	CB	N6070	Sc	CB
N4682	Sc	SSN	N5247	Sc	CB:	N5633	Sbc	SSN	N6118	Sc	CB
N4689	Sc	CB:	N5297	Sc	CB	N5653	Sc	SSN	N6181	Sc	CB:
New 3	SBcd	Tr	N5301	Sc	CB	N5660	Sc	SSN	N6217	SBbc	CB
N4712	Sc	SSN	N5313	S:	CB:	N5645	Sc	NB	N6207	Sc	N
N4731	SBc	NB	N5324	Sbc	SSN	N5643	SBc	CB	N6239	SBc	Tr
N4763	SBbc	CB:	N5334	SB:	Tr	N5669	Sc	NB	N6412	SBc	CB:
N4790	Sd	Tr:	N5347	SBb	CB	N5676	Sc	CB	I4662	Im	NN
New 4	Sc	SSN	N5350	SBbc	CB	N5690	Sc	NN	N6503	Sc	N
N4861	SBm	NN	N5351	SBb	SSN	N5728	SBb	CB	N6574	Sbc	SSN:
N4891	SBbc	CB	N5362	S	CB	N5756	Sc	SSN	N6643	Sc	SSN
N4928	Sbc	SSN	N5376	Sbc	CB	N5768	Sc	SSN	I4710	SBd	NN
N4939	Sbc	CB	HA 72	Sc	Tr	N5775	Sc	Tr?	I4721	Sc	CB
N4945	Sc	NN	N5406	Sc	CB:	N5792	SBb	CB:	N6699	Sbc	CB:
N4947	Sbc	SSN	N5398	SBc	SSN:	F 703	Sc	CB	N6744	Sbc	CB
N4981	SBbc	CB	N5426	Sbc	CB:	N5885	SBc	CB	N6780	Sbc	CB
N4999	SBb	CB	N5427	Sbc	CB:	N5899	Sc	CB	N6808	Sc	CB
N4995	Sbc	CB:	N5457	Sc	CB:	N5905	SBb	CB	N6814	Sbc	CB:

Galaxy	Hubble Type		Galaxy	Hubble Type		Galaxy	Hubble Type	
N6822	Im	NN	N7171	Sb	CB	N7462	SBc	NB:
N6878	Sc	CB	I5152	Sdm	Tr	N7479	SBbc	CB:
N6923	SBbc	CB:	I5201	SBcd	NB:	N7496	SBc	CB
N6925	Sbc	CB	N7300	Sc	CB	N7541	Sc	NB:
N6946	Sc	CB	N7307	SBc	Tr	N7640	SBc	CB
N6951	Sb	NB:	N7309	Sc	CB	N7689	Sc	SSN
I5039	Sc	N?	N7314	Sc	SSN	I5332	Sc	CB
I5052	Sd	NN	N7329	SBcd	CB	N7721	Sbc	SSN:
N6970	Sc	N	N7361	Sc	NN?	N7723	SBb	CB
N6984	SBbc	CB:	N7418	Sc	CB:	N7741	SBc	NB
N7038	Sbc	CB	N7421	SBcd	CB	N7755	SBbc	CB
N7064	Scd	NN	N7424	Sc	NB	N7793	Sd	SSN
N7070	SBc	CB	I5273	SBc	CB			
N7124	Sbc	CB	N7448	Sc	CB			
N7137	Sc	SSN	N7456	Sc	SSN?			

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FIGURE LEGENDS

Fig. 1 Magnitude versus Hubble type diagram for late-type galaxies of type CB, which have bright central bulges. Most of these galaxies are seen to have Hubble types Sb-Sc and $M_B < -20$.

Fig. 2 Magnitude versus Hubble type diagram for late-type galaxies of type NN, which do not have nuclei. Most of these objects are seen to have Hubble types Sc-Sd-Sm-Im and $M_B > -20$.

Fig. 3 Luminosity distribution for CB galaxies (left) and for NN galaxies (right). The Figure shows that galaxies with small bright central bulges are more luminous than those that do not have nuclei.

Fig. 4 Luminosity distribution of spiral and irregular galaxies in the Kraan-Korteweg & Tammann (1979) catalog of nearby galaxies. Most spirals are seen to be brighter than $M_B = -17$, whereas the majority of irregulars are fainter than this limit.

Fig. 5 I-band CFHT exposure of NGC 4449 obtained by Pritchet and van den Bergh in 1984. The image was obtained with a 320 x 512 RCA chip having a scale of 0.41 arcsec/pixel. The nucleus is marked by an arrow. Note that this may be a rare example of an irregular galaxy that appears to contain a nucleus.